Optimizing the control of foot-and-mouth disease in Denmark by simulation

Comparison of different control strategies on FMD in Denmark

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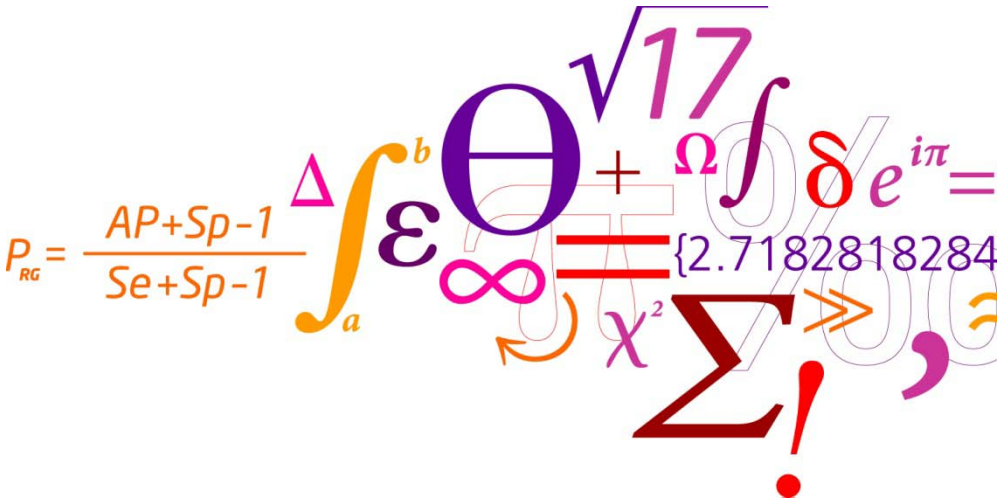


DTU Vet
National Veterinary Institute

Control scenarios

- Basic

- Depopulation in zones (**Depop**)
  - varying starting point
  - varying radius

- Suppressiv vaccination in zones (**Vac-to-Kill**)
  - varying starting point
  - varying radius

- Protective vaccination in zones (**Vac-to-Live**)
  - varying starting point
  - varying radius

More scenarios

- Depop/Vac – but not in hobby farms
- Vacciation – but not in sheep OR swine
- Simulating airborne spread – on diff. scenarios
- Changing size of protection and/or surveilance zones
- Outdoor farming – as special case
- Leading to around 100 scenarios…..
- PLUS Sensitivity analysis (ca. 30)

Results

- Epidemiologic results
  - Infected herds
  - Detected herds
  - Duration of epidemic
    - from first to last detection
  - Depopulated herds
  - Vaccinated herds

- Economic results
  - 37 outputs (costs and losses)
  - Only total costs and losses are shown here!

Epidemiologic results - CattleHigh

Control strategy Results as median (5-95)		Epidemic duration (days)[1]		Infected herds	
		DTU-DADS	ISP	DTU-DADS	ISP
Basic	-	56 (16-142)	80 (5-255)	67 (13-245)	137 (3-696)
Depop14D	500 m	46 (16-100)	66 (5-184)	59 (12-177)	109 (3-469)
Depop14D	1000 m	40 (16-83)	48 (5-122)	54 (12-154)	79 (3-314)
Depop14D	1500 m	37 (16-77)	42 (5-107)	51 (11-146)	72 (3-289)
Depop10H	500 m	44 (15-97)	65 (5-178)	53 (12-151)	101 (3-426)
Depop10H	1000 m	35 (14-75)	46 (5-123)	45 (12-128)	76 (3-287)
Depop10H	1500 m	33 (14-67)	41 (5-102)	43 (12-108)	66 (3-269)

Epidemiologic results - CattleHigh

Control strategy Results as median (5-95)		Epidemic duration (days)		Infected herds	
		DTU-DADS	ISP	DTU-DADS	ISP
VacToKill14days	1km	47 (16-100)	59 (5-141)	60 (12-193)	93 (3-368)
	2km	42 (16-78)	49 (5-110)	56 (12-172)	74 (3-303)
	3km	40 (16-72)	47 (5-104)	54 (12-160)	74 (3-269)
	5km	40 (16-72)	46 (5-94)	53 (12-153)	71 (3-262)
VacToKill10herds	1km	42 (16-90)	58 (5-136)	56 (13-154)	86 (3-346)
	2km	38 (16-77)	48 (5-110)	51 (12-140)	69 (3-245)
	3km	35 (15-68)	44 (5-97)	49 (13-129)	66 (3-227)
	5km	33 (15-61)	42 (5-89)	47 (12-120)	65 (3-205)
VacToLive14days	1km	45 (15-93)	53 (5-125)	61 (11-183)	80 (3-304)
	2km	42 (13-76)	46 (5-97)	54 (10-156)	69 (3-261)
	3km	38 (15-73)	42 (5-87)	53 (11-144)	64 (3-233)
	5km	37 (15-63)	40 (5-81)	50 (11-136)	56 (3-207)
VacToLive10herds	1km	43 (15-88)	53 (5-133)	55 (11-158)	81 (3-303)
	2km	35 (13-72)	43 (5-101)	48 (10-136)	64 (3-227)
	3km	34 (15-61)	39 (5-86)	46 (11-119)	57 (3-195)
	5km	32 (14-58)	37 (5-78)	43 (11-110)	52 (3-174)

Economics

Eco res – comparing depop scenarios

Economy - means (mill. €)		CattleHigh	CattleLow	PigHigh	PigLow	Sheep
Basic		702.7	613.0	508.0	504.9	457.5
Depop14days	500m	634.4	559.3	474.4	475.1	443.1
	1000m					
	1500m					
Depop10herds	500m	627.0	564.6	475.7	477.1	447.1
	1000m					
	1500m					
Depop20herds	500m	629.5	563.4	484.4	485.1	445.8
	1000m					
	1500m					
Depop30herds	500m	635.0	566.0	489.0	491.1	446.1
	1000m					
	1500m					
Depop50herds	500m	643.1	573.5	494.1	489.5	449.4
	1000m					
	1500m					

Eco res – comparing depop and zone size

Economy - means (mill. €)		CattleHigh	CattleLow	PigHigh	PigLow	Sheep
Basic		**702.7**	**613.0**	**508.0**	**504.9**	**457.5**
Depop14days	500m	**634.4**	**559.3**	**474.4**	**475.1**	**443.1**
	1000m	**565.2**	**514.5**	**452.3**	**452.0**	**419.2**
	1500m	**566.2**	**498.1**	**441.2**	**440.0**	**415.7**
Depop10herds	500m					
	1000m					
	1500m					
Depop20herds	500m					
	1000m					
	1500m					
Depop30herds	500m					
	1000m					
	1500m					
Depop50herds	500m					
	1000m					
	1500m					

Eco res – comparing ALL depop

Economy - means (mill. €)		CattleHigh	CattleLow	PigHigh	PigLow	Sheep
Basic		702.7	613.0	508.0	504.9	457.5
Depop14days	500m	634.4	559.3	474.4	475.1	443.1
	1000m	565.2	514.5	452.3	452.0	419.2
	1500m	566.2	498.1	441.2	440.0	415.7
Depop10herds	500m	627.0	564.6	475.7	477.1	447.1
	1000m	561.5	516.8	453.6	450.5	428.6
	1500m	552.2	499.6	441.9	442.8	420.1
Depop20herds	500m	629.5	563.4	484.4	485.1	445.8
	1000m	573.2	521.7	459.9	459.8	431.7
	1500m	562.8	509.5	452.6	454.3	425.3
Depop30herds	500m	635.0	566.0	489.0	491.1	446.1
	1000m	573.5	533.1	473.5	478.7	446.4
	1500m	563.2	512.1	461.6	459.2	429.8
Depop50herds	500m	643.1	573.5	494.1	489.5	449.4
	1000m	591.4	536.1	474.5	470.8	434.8
	1500m	573.9	527.7	470.6	467.9	435.4

Eco res – comparing VacToKill scenarios

Economy - means (mill. €)		CattleHigh	CattleLow	PigHigh	PigLow	Sheep
Basic		702.7	613.0	508.0	504.9	457.5
Vaccination 14days	1km	588.1	528.9	462.5	468.2	428.4
	2km					
	3km					
	5km					
Vaccination 10herds	1km	579.6	535.3	468.7	475.7	437.7
	2km					
	3km					
	5km					
Vaccination 20herds	1km	600.3	539.8	470.2	472.4	424.3
	2km					
	3km					
	5km					
Vaccination 30herds	1km	596.7	541.6	469.9	478.6	441.8
	2km					
	3km					
	5km					
Vaccination 50herds	1km	605.0	560.8	484.6	488.9	444.0
	2km					
	3km					
	5km					

Eco res – comparing VacToKill - zones

Economy - means (mill. €)		CattleHigh	CattleLow	PigHigh	PigLow	Sheep
Basic		702.7	613.0	508.0	504.9	457.5
Vaccination 14days	1km	588.1	528.9	462.5	468.2	428.4
	2km	579.0	506.2	444.3	451.4	422.4
	3km	563.3	499.5	444.2	446.5	415.9
	5km	577.0	508.1	445.9	462.4	421.4
Vaccination 10herds	1km					
	2km					
	3km					
	5km					
Vaccination 20herds	1km					
	2km					
	3km					
	5km					
Vaccination 30herds	1km					
	2km					
	3km					
	5km					
Vaccination 50herds	1km					
	2km					
	3km					
	5km					

Eco res – comparing VacToKill -ALL

Economy - means (mill. €)		CattleHigh	CattleLow	PigHigh	PigLow	Sheep
Basic		702.7	613.0	508.0	504.9	457.5
Vaccination 14days	1km	588.1	528.9	462.5	468.2	428.4
	2km	579.0	506.2	444.3	451.4	422.4
	3km	563.3	499.5	444.2	446.5	415.9
	5km	577.0	508.1	445.9	462.4	421.4
Vaccination 10herds	1km	579.6	535.3	468.7	475.7	437.7
	2km	553.2	520.2	449.8	458.8	422.8
	3km	545.9	524.0	449.0	470.9	426.1
	5km	564.0	540.6	455.9	478.4	429.8
Vaccination 20herds	1km	600.3	539.8	470.2	472.4	424.3
	2km	554.2	521.0	457.4	470.5	430.4
	3km	554.1	530.5	464.9	469.0	431.4
	5km	565.6	543.8	458.9	485.5	437.4
Vaccination 30herds	1km	596.7	541.6	469.9	478.6	441.8
	2km	574.2	526.5	461.7	469.7	431.1
	3km	565.8	530.9	458.9	476.3	434.1
	5km	578.4	541.4	460.5	512.8	434.1
Vaccination 50herds	1km	605.0	560.8	484.6	488.9	444.0
	2km	578.1	535.4	481.8	511.1	441.6
	3km	573.9	536.8	484.3	514.6	445.0
	5km	577.9	548.4	499.0	531.0	456.8

Eco res – comparing VacToLive scenarios

Economy - means (mill. €)		CattleHigh	CattleLow	PigHigh	PigLow	Sheep
Basic		702.7	613.0	508.0	504.9	457.5
VacToLive 14days	1km	647.4	596.9	533.7	532.7	504.3
	2km					
	3km					
	5km					
VacToLive 10herds	1km	646.4	597.0	540.9	538.3	507.9
	2km					
	3km					
	5km					
VacToLive 20herds	1km	653.8	604.5	543.9	539.3	510.8
	2km					
	3km					
	5km					
VacToLive 30herds	1km	660.1	613.7	543.7	545.0	513.4
	2km					
	3km					
	5km					
VacToLive 50herds	1km	666.5	619.2	550.2	544.6	518.1
	2km					
	3km					
	5km					

Eco res – comparing VacToLive - zones

Economy - means (mill. €)		CattleHigh	CattleLow	PigHigh	PigLow	Sheep
Basic		702.7	613.0	508.0	504.9	457.5
VacToLive 14days	1km	647.4	596.9	533.7	532.7	504.3
	2km	614.5	574.1	517.5	518.8	495.4
	3km	605.5	565.0	512.7	512.4	489.2
	5km	601.9	557.7	516.6	509.6	489.5
VacToLive 10herds	1km					
	2km					
	3km					
	5km					
VacToLive 20herds	1km					
	2km					
	3km					
	5km					
VacToLive 30herds	1km					
	2km					
	3km					
	5km					
VacToLive 50herds	1km					
	2km					
	3km					
	5km					

Eco res – comparing VacToLive - ALL

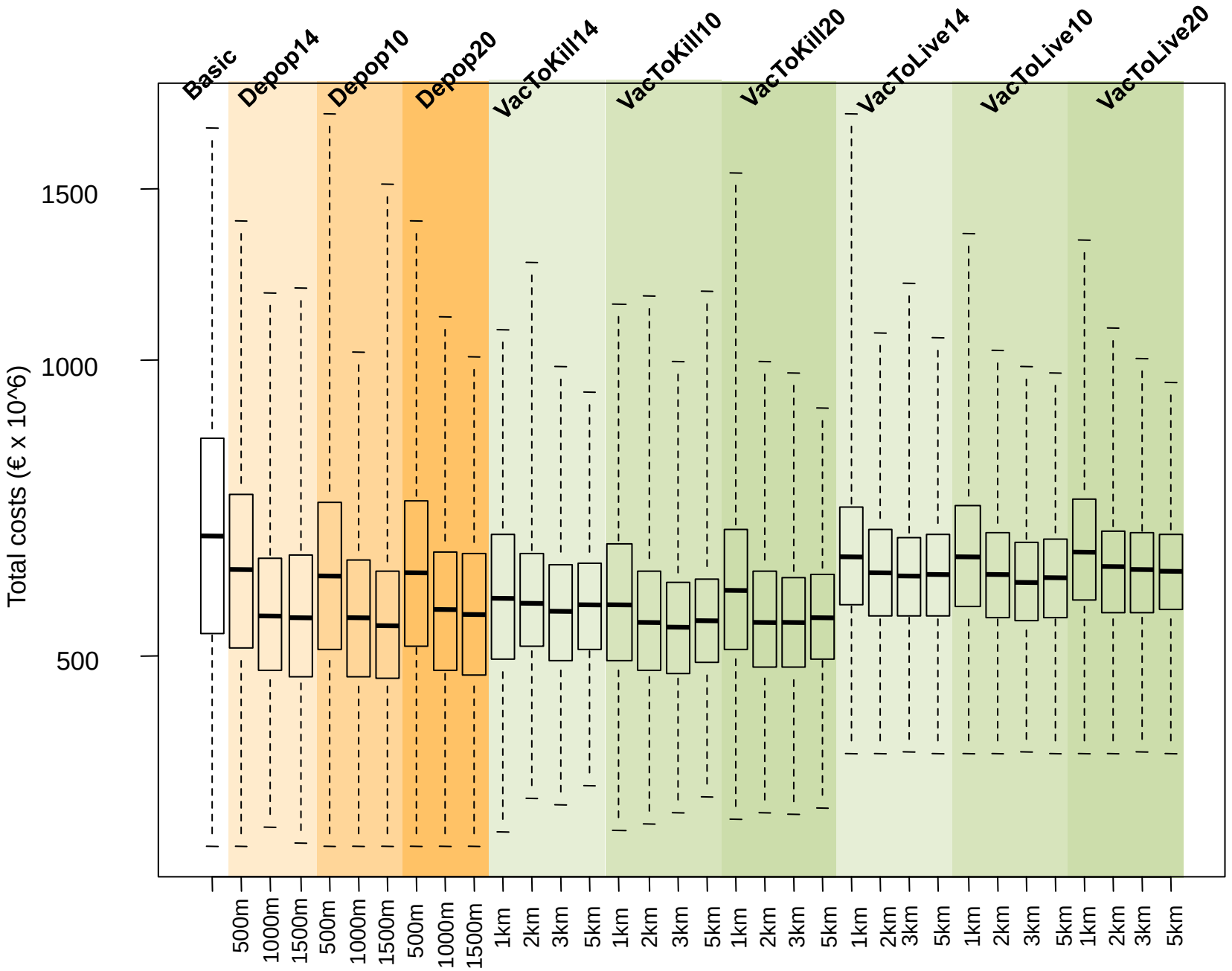
Economy - means (mill. €)		CattleHigh	CattleLow	PigHigh	PigLow	Sheep
Basic		702.7	613.0	508.0	504.9	457.5
VacToLive 14days	1km	647.4	596.9	533.7	532.7	504.3
	2km	614.5	574.1	517.5	518.8	495.4
	3km	605.5	565.0	512.7	512.4	489.2
	5km	601.9	557.7	516.6	509.6	489.5
VacToLive 10herds	1km	646.4	597.0	540.9	538.3	507.9
	2km	608.4	569.3	522.5	521.3	498.9
	3km	596.3	557.7	519.9	517.6	496.0
	5km	595.0	554.0	520.3	514.0	494.6
VacToLive 20herds	1km	653.8	604.5	543.9	539.3	510.8
	2km	616.0	576.3	533.6	526.3	504.9
	3km	609.5	568.3	527.3	520.4	500.4
	5km	602.3	563.9	528.3	521.2	499.0
VacToLive 30herds	1km	660.1	613.7	543.7	545.0	513.4
	2km	618.6	583.0	535.8	532.0	509.3
	3km	608.8	574.8	534.7	527.2	506.7
	5km	608.2	566.0	530.8	526.2	503.3
VacToLive 50herds	1km	666.5	619.2	550.2	544.6	518.1
	2km	633.8	591.2	546.3	537.8	512.8
	3km	622.8	585.0	541.0	532.7	511.1
	5km	619.5	578.9	538.5	532.9	507.8

Eco res –depop and vac

Economy - means (mill. €)		CattleHigh	CattleLow	PigHigh	PigLow	Sheep
Basic		702.7	613.0	508.0	504.9	457.5
Depopulation 14days	500m	634.4	559.3	474.4	475.1	443.1
	1000m	565.2	514.5	452.3	452.0	419.2
	1500m	566.2	498.1	441.2	440.0	415.7
Depopulation 10herds	500m	627.0	564.6	475.7	477.1	447.1
	1000m	561.5	516.8	453.6	450.5	428.6
	1500m	552.2	499.6	441.9	442.8	420.1
Vaccination 14days	1km	588.1	528.9	462.5	468.2	428.4
	2km	579.0	506.2	444.3	451.4	422.4
	3km	563.3	499.5	444.2	446.5	415.9
Vaccination 10herds	1km	579.6	535.3	468.7	475.7	437.7
	2km	553.2	520.2	449.8	458.8	422.8
	3km	545.9	524.0	449.0	470.9	426.1
VacToLive 14days	1km	647.4	596.9	533.7	532.7	504.3
	2km	614.5	574.1	517.5	518.8	495.4
	3km	605.5	565.0	512.7	512.4	489.2
VacToLive 10herds	1km	646.4	597.0	540.9	538.3	507.9
	2km	608.4	569.3	522.5	521.3	498.9
	3km	596.3	557.7	519.9	517.6	496.0

Eco res –depop and vac

Economy - means (mill. €)		CattleHigh		CattleLow		PigHigh		PigLow		Sheep	
Basic		606.4	702.7	651.6	613.0	541.4	508.0	545.4	504.9	523.8	457.5
Depopulation 14days	500m	557.5	634.4	566.7	559.3	505.9	474.4	504.6	475.1	496.6	443.1
	1000m	531.9	565.2	529.6	514.5	487.1	452.3	482.7	452.0	472.3	419.2
	1500m	524.6	566.2	516.8	498.1	479.8	441.2	474.0	440.0	464.6	415.7
Depopulation 10herds	500m	543.7	627.0	550.5	564.6	495.0	475.7	495.1	477.1	488.1	447.1
	1000m	514.2	561.5	511.3	516.8	473.6	453.6	469.6	450.5	462.4	428.6
	1500m	507.2	552.2	500.0	499.6	465.8	441.9	463.3	442.8	457.7	420.1
Vaccination 14days	1km	558.4	588.1	568.5	528.9	501.1	462.5	499.0	468.2	492.5	428.4
	2km	542.0	579.0	542.8	506.2	494.3	444.3	489.7	451.4	483.9	422.4
	3km	544.0	563.3	541.5	499.5	494.8	444.2	485.3	446.5	484.2	415.9
Vaccination 10herds	1km	541.1	579.6	546.3	535.3	497.5	468.7	496.3	475.7	484.1	437.7
	2km	530.1	553.2	525.2	520.2	483.5	449.8	479.4	458.8	476.3	422.8
	3km	529.3	545.9	528.1	524.0	482.6	449.0	478.1	470.9	474.5	426.1
VacToLive 14days	1km	632.9	647.4	641.2	596.9	580.4	533.7	578.8	532.7	566.9	504.3
	2km	616.6	614.5	619.8	574.1	570.5	517.5	565.5	518.8	556.9	495.4
	3km	610.7	605.5	612.1	565.0	564.2	512.7	560.8	512.4	555.1	489.2
VacToLive 10herds	1km	616.0	646.4	625.1	597.0	571.6	540.9	568.2	538.3	559.5	507.9
	2km	596.7	608.4	592.8	569.3	558.5	522.5	558.0	521.3	549.3	498.9
	3km	588.9	596.3	587.0	557.7	551.6	519.9	548.8	517.6	543.5	496.0


Basic
Depop14
Depop10
Depop20
VacToKill14
VacToKill10
VacToKill20
VacToLive14
VacToLive10
VacToLive20
Total costs (€ x 10^6)
1500
1000
500
500m
1000m
1500m
500m
1000m
1500m
500m
1000m
1500m
1km
2km
3km
5km
1km
2km
3km
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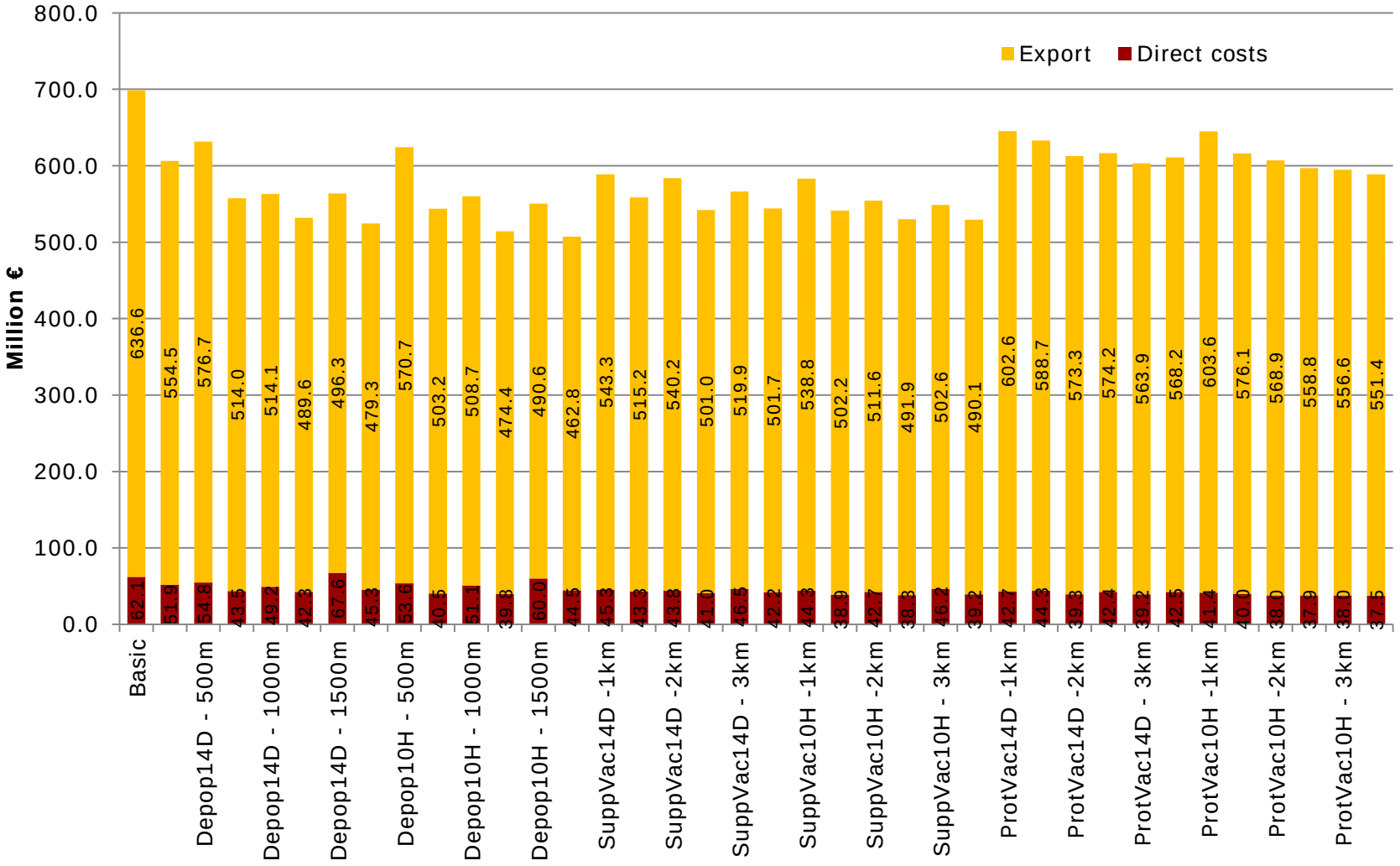
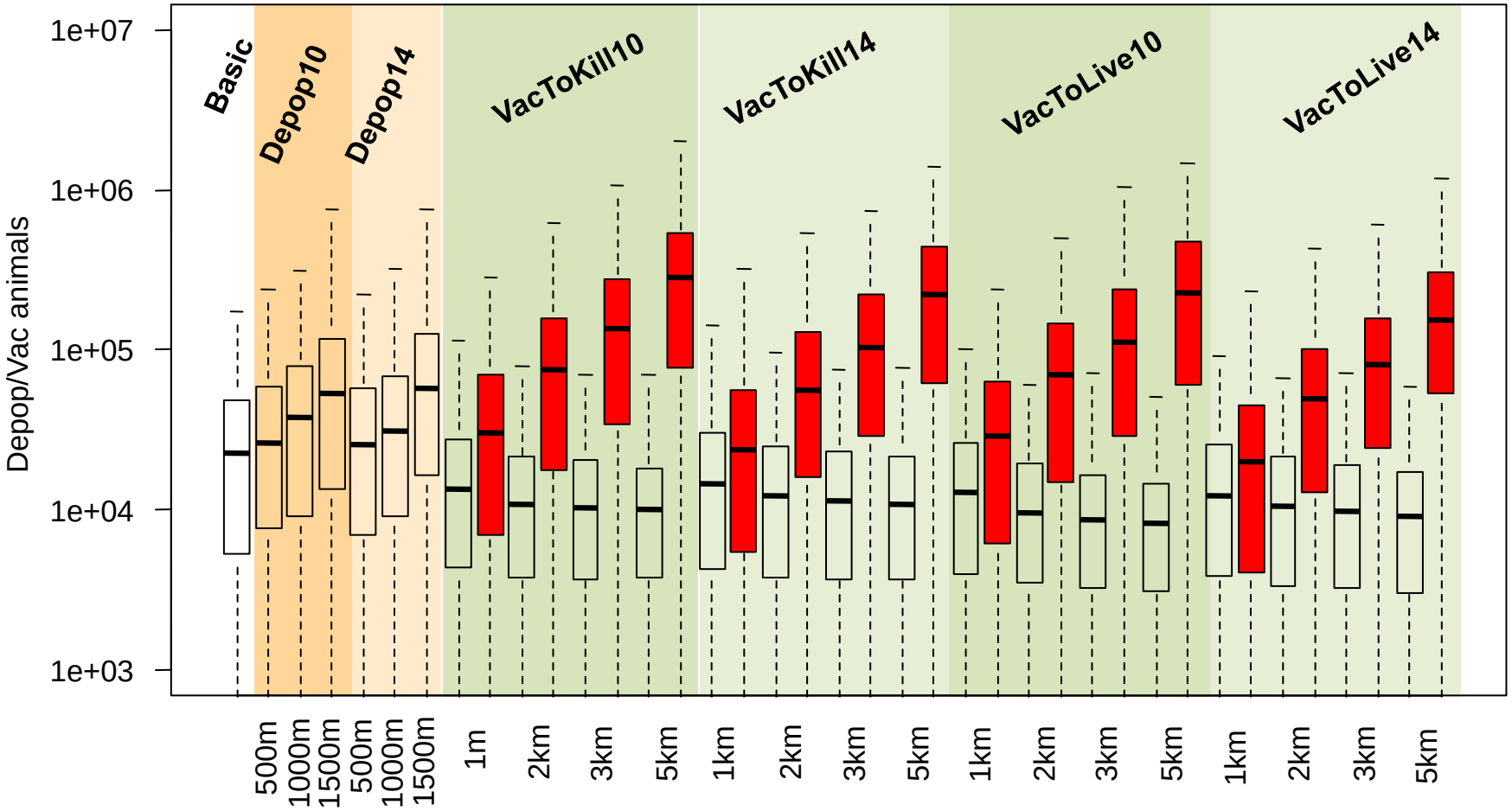
3km
5km
1km
2km
3km
5km

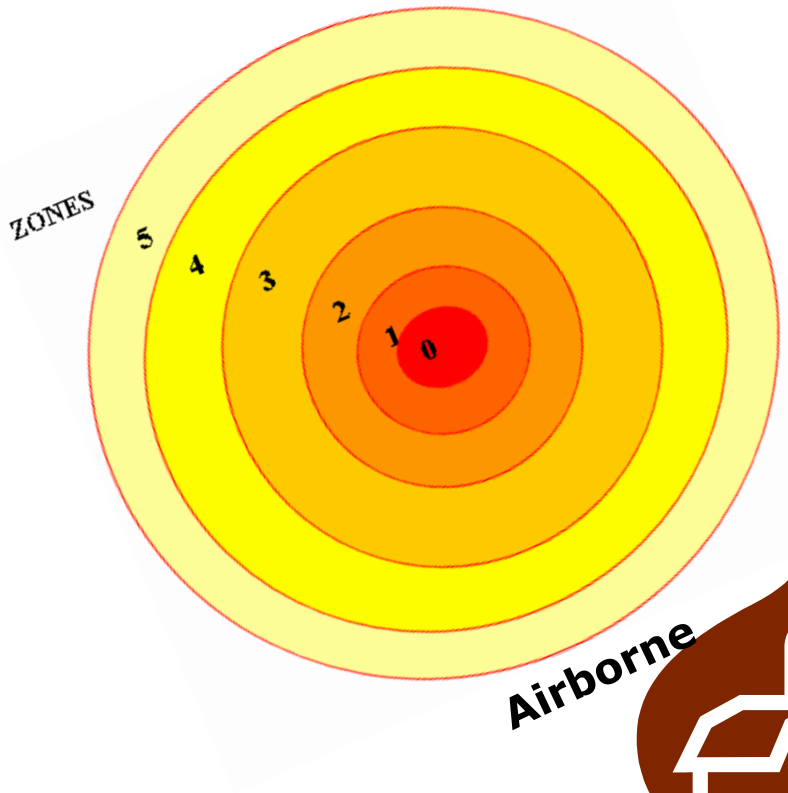
Costs and losses, ISP + DTU-DADS



Ethics – numbers of depopulated animals



Other scenarios

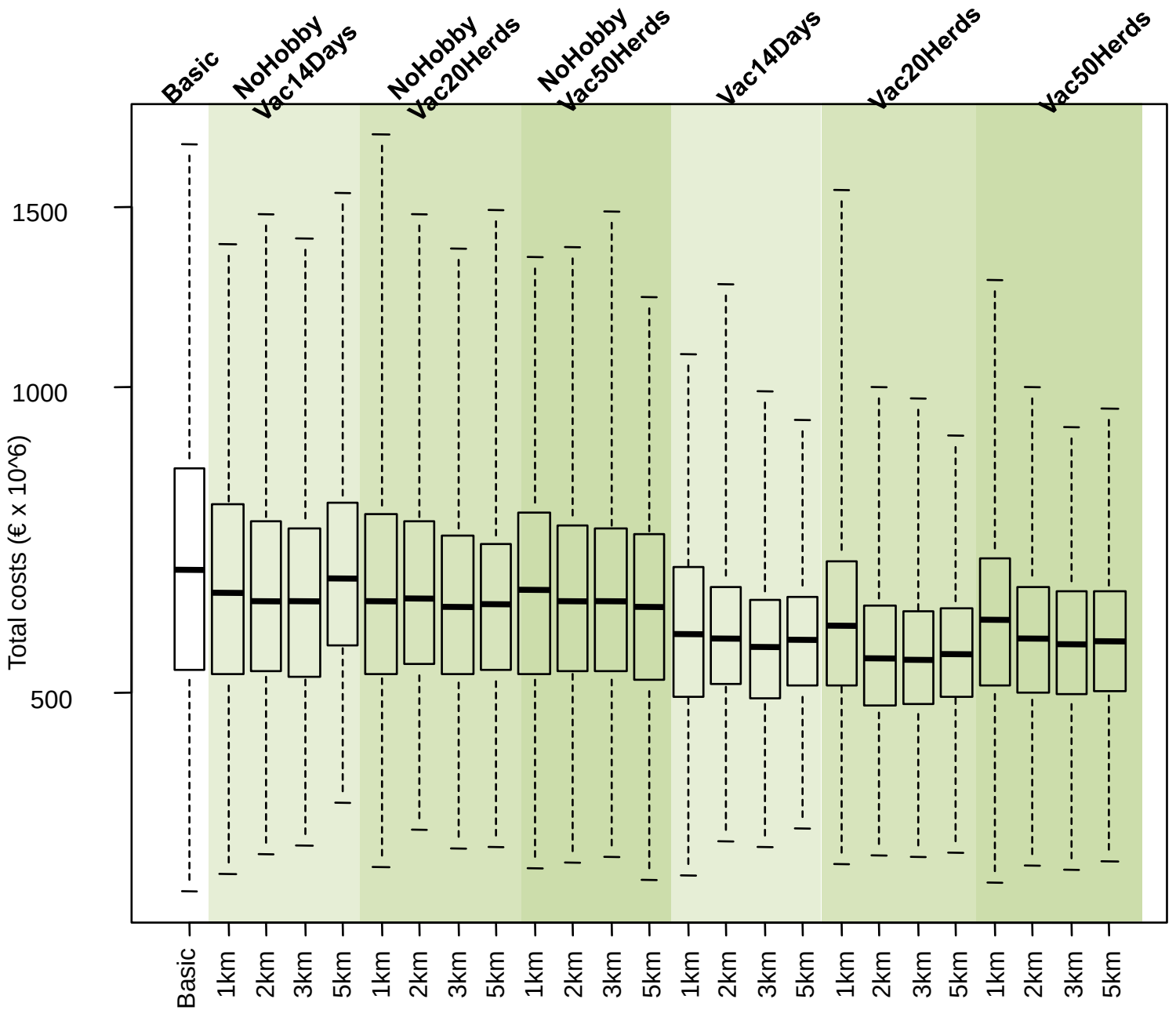


Hobby farms

Airborne

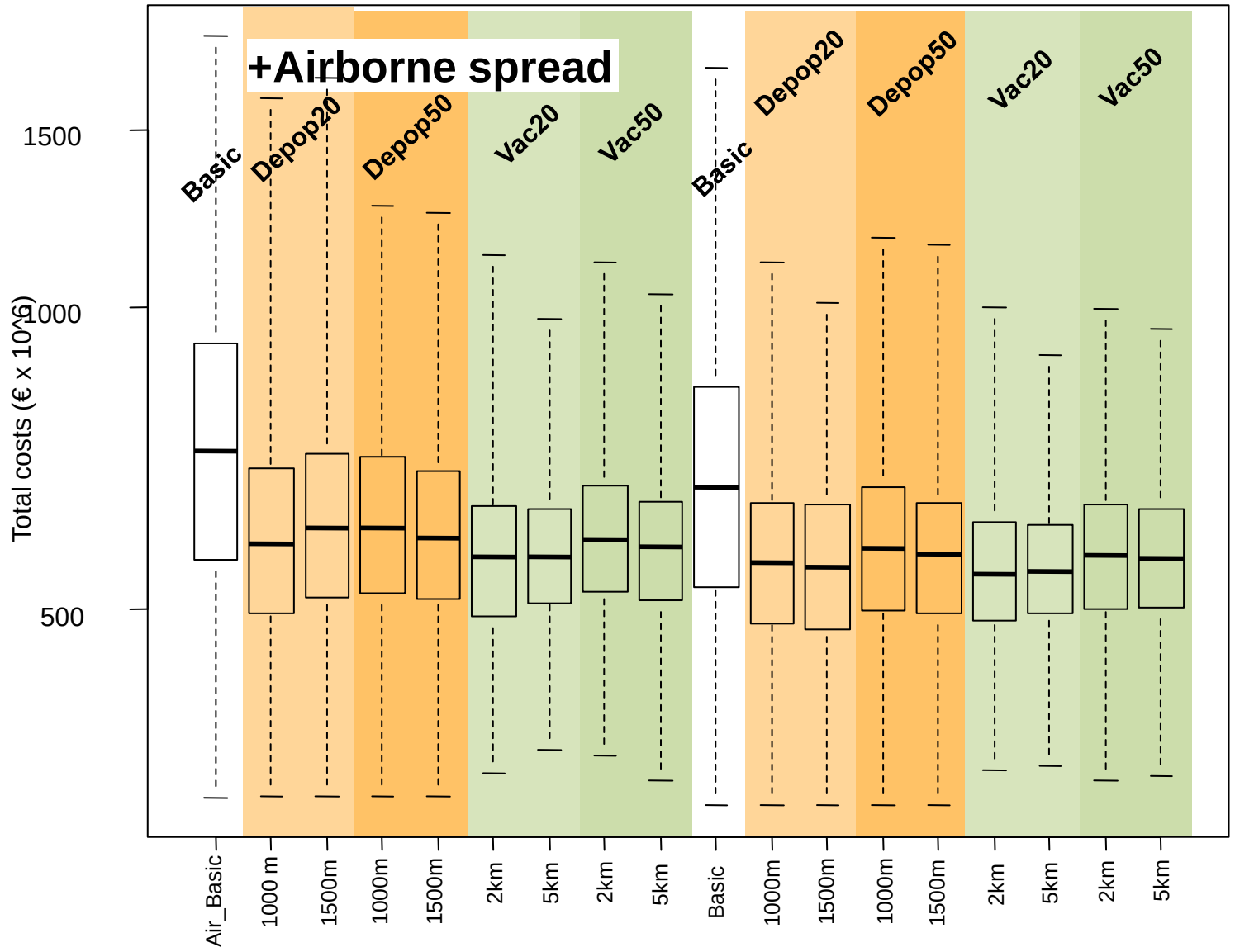
No depopulation in hobby farms

Economy - means (mill. €)		CattleHigh	CattleLow	PigHigh	PigLow	Sheep
Basic		698.7	610.1	506.4	503.4	456.7
Depop14days	500m	631.5	557.2	473.2	474.0	442.6
	1000m	563.3	513.1	451.4	451.2	418.8
	1500m	563.9	496.8	440.4	439.2	415.4
Depop14days	500m	**691.8**	**595.6**	**492.5**	**499.6**	**457.2**
(no depop of	1000m	**645.4**	**587.8**	**477.7**	**482.1**	**451.5**
hobby farms)	1500m	**658.7**	**572.5**	**471.5**	**483.2**	**446.5**
Depop20herds	500m	626.8	561.3	483.1	483.9	445.2
	1000m	571.3	520.2	458.8	458.9	431.3
	1500m	561.1	508.2	451.7	453.5	425.0
Depop20herds	500m	**672.5**	**598.8**	**495.2**	**494.5**	**448.8**
(no depop of	1000m	**655.9**	**592.8**	**502.0**	**503.5**	**465.9**
hobby farms)	1500m	**647.7**	**576.9**	**486.5**	**483.3**	**446.7**
Depop50herds	500m	640.2	571.3	492.7	488.2	448.7
	1000m	589.3	534.4	473.4	469.8	434.3
	1500m	572.0	526.1	469.5	466.9	434.9
Depop50herds	500m	**687.6**	**614.7**	**501.1**	**503.4**	**458.8**
(no depop of	1000m	**656.1**	**591.6**	**496.8**	**492.0**	**451.8**
hobby farms)	1500m	**663.3**	**598.3**	**504.8**	**503.8**	**465.2**


Basic
NoHobby Vac14Days
NoHobby Vac20Herds
NoHobby Vac50Herds
Vac14Days
Vac20Herds
Vac50Herds
1500
1000
500
Total costs (€ x 10^6)
Basic
1km
2km
3km
5km

Adding airborne spread

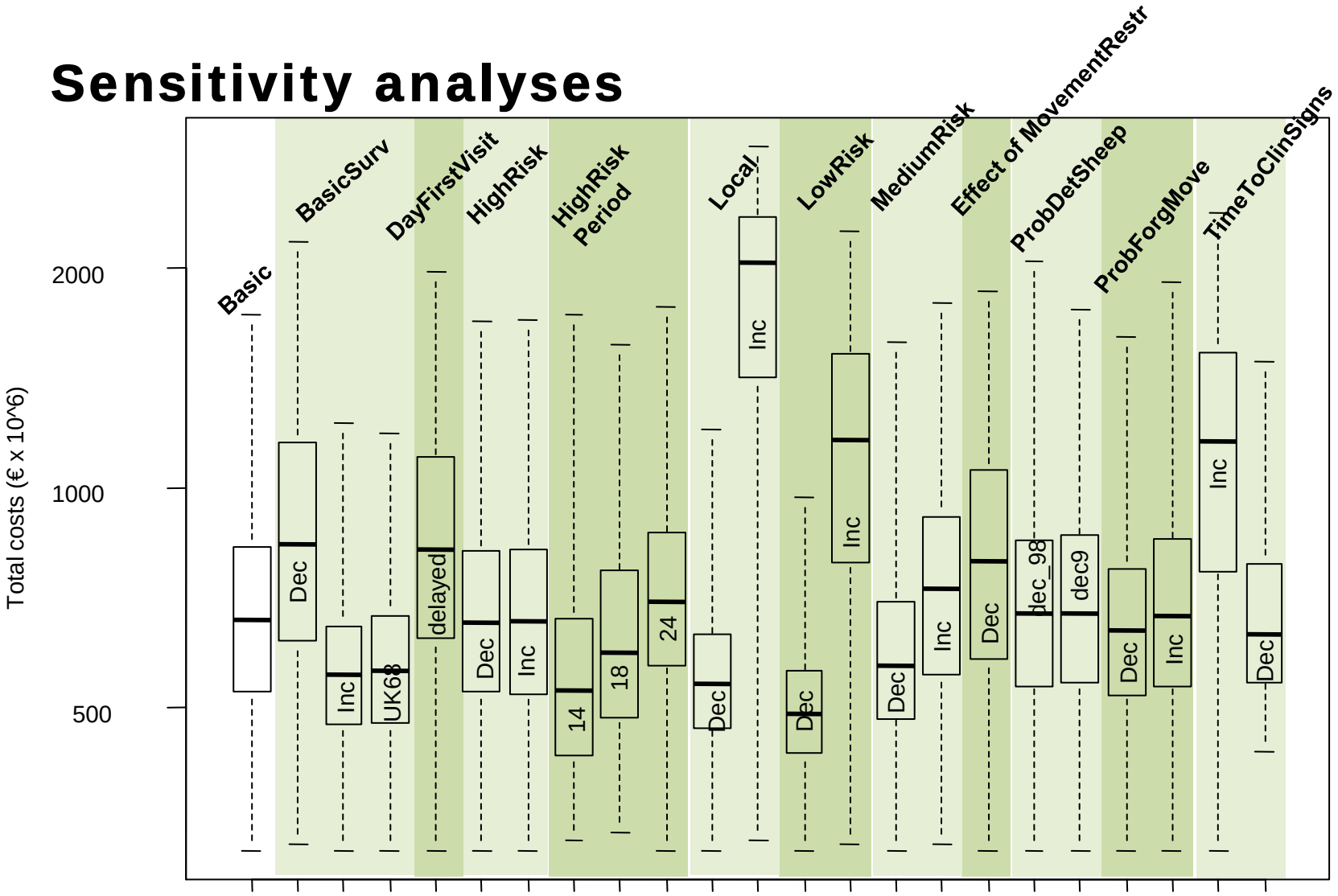
Economy - means (mill. €)		CattleHigh	CattleLow	PigHigh	PigLow	Sheep
Basic		698.7	610.1	506.4	503.4	456.7
Basic + airborne		**767.8**	**664.1**	**568.9**	**556.3**	**487.7**
Depopulation	1000m	571.3	520.2	458.8	458.9	431.3
20herds	1500m	561.1	508.2	451.7	453.5	425.0
Depop20herd	1000m	**605.5**	**541.6**	**486.4**	**485.4**	**438.1**
+ airborne	1500m	**628.2**	**552.9**	**487.8**	**486.1**	**431.7**
Depopulation	1000m	589.3	534.4	473.4	469.8	434.3
50herds	1500m	572.0	526.1	469.5	466.9	434.9
Depop50herd	1000m	**622.8**	**560.3**	**504.1**	**492.5**	**441.9**
+ airborne	1500m	**607.9**	**550.1**	**493.8**	**489.3**	**439.1**
Vaccination	2km	555.0	521.7	459.3	471.9	431.9
20herds	5km	568.4	544.3	462.3	486.9	438.3
Vacc20herds	2km	**575.4**	**586.3**	**484.3**	**486.6**	**440.0**
+airborne	5km	**587.2**	**610.1**	**508.4**	**500.1**	**462.5**
Vaccination	2km	576.4	536.0	482.5	511.7	441.7
50herds	5km	579.6	550.6	500.2	531.7	457.9
Vacc50herds	2km	**602.8**	**624.4**	**498.5**	**487.2**	**450.0**
+airborne	5km	**594.8**	**665.7**	**559.5**	**492.5**	**476.8**


+Airborne spread
Total costs (€ x 10^6)
1500
1000
500
Basic
Depop20
Depop50
Vac20
Vac50
Basic
Depop20
Depop50
Vac20
Vac50
Air_Basic
1000 m
1500m
1000m
1500m
2km
5km
2km
5km
Basic
1000m
1500m
1000m
1500m
2km
5km
2km
5km

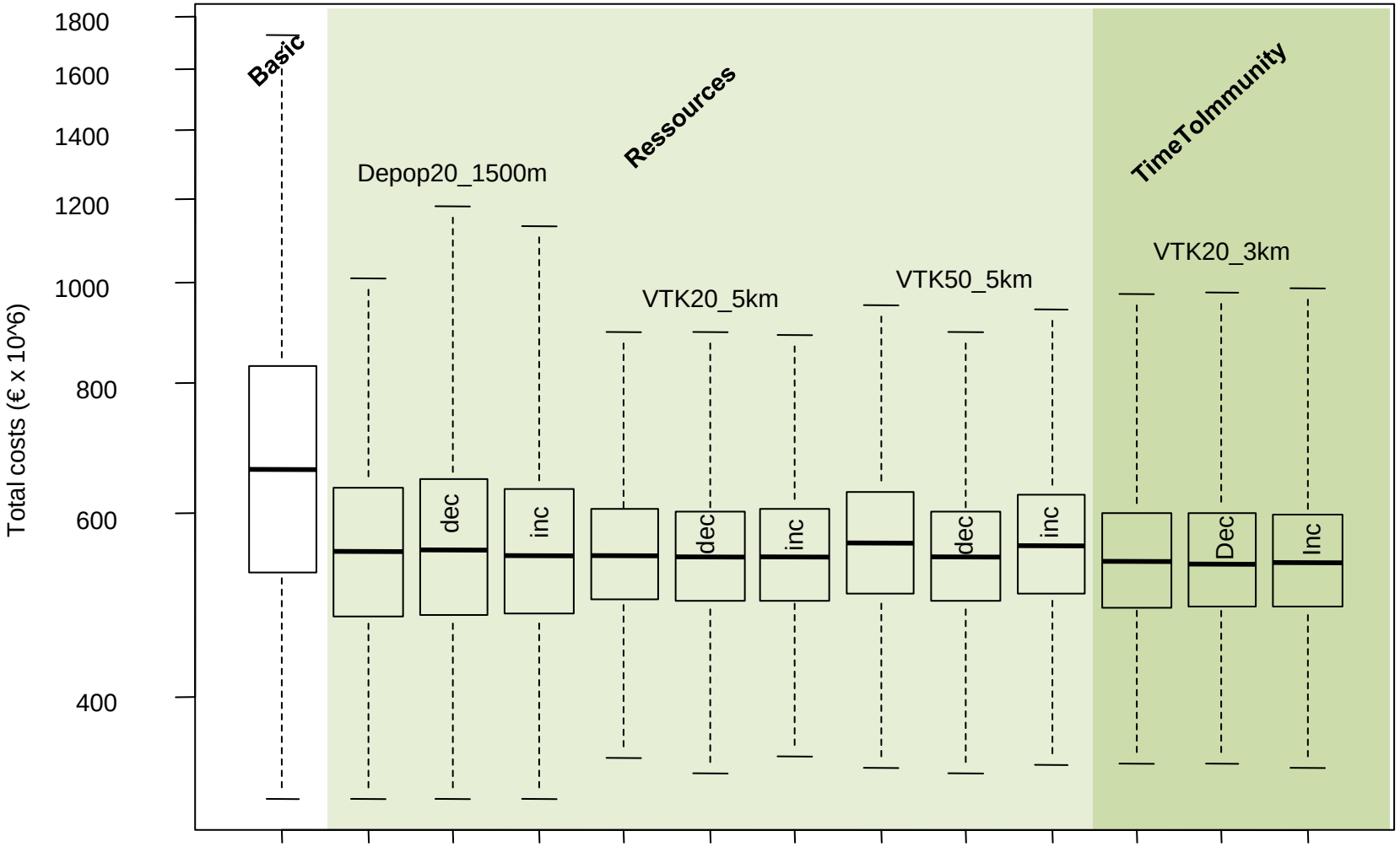
Comparing changed zone sizes

Economic results in means (mill. €)		CattleHigh	CattleLow	PigHigh	PigLow	Sheep
Basic		**702.7**	**613.0**	**508.0**	**504.9**	**457.5**
Protection zone increased	5km	**706.6**	**633.7**	**521.4**	**507.0**	**467.0**
Surveillance zone increased	15km	**608.4**	**550.7**	**484.8**	**472.2**	**444.4**
	20km	**587.0**	**519.1**	**473.8**	**464.4**	**436.4**
Protection and surveillance zone increased	5/15km	**629.0**	**556.7**	**492.5**	**479.0**	**444.9**

Sensitivity analyses



Sensitivity analyses



Conclusions

- **Extra control meassures** will most often reduce size, duration and costs of an FMD epidemic in Denmark

- **Depopulation** in zones is preferable
  - In cattle dense area
    - suppressive vaccination less costly in one model
  - **However** – be aware of the large number of animals to slaughter!

- **Protective vaccination** prefereable from an **epidemiological** point of view
  - BUT **NEVER** from an **economic** point of view!

- **Airborne spread**
  - larger and longer epidemics
  - control strategy will be the same

Conclusions - 2

- Not depopulating or vaccinating in hobby farms
  - Lead to more expensive epidemics

- Enlarging surveillance zones
  - Lead to less costly epidemics

Thank you for your attention